A Conjecture On the Origin of Quantum Electrodynamics and of Colours

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Abstract

The strand conjecture proposes a specific Planck-scale model of nature that allows deducing the entire standard model of particle physics. The conjecture derives from an idea popularized by Dirac and models particles as rational tangles. Using the results of Battey-Pratt and Racey, the strand conjecture explains the Dirac equation. Tangle classification implies the observed particle spectrum of bosons and fermions. The specific tangles for each elementary particle determine a unique value for spin, the other quantum numbers, mixing angles and particle masses. Using the results of Reidemeister, tangle deformations induce the three observed gauge interactions, including their symmetry groups. Because the particle tangles yield only the observed Feynman diagrams, without any additions or modifications, the complete Lagrangian of the standard model arises, including that of quantum electrodynamics.

The conjectured QED process that occurs at interaction vertices at the Planck scale suggests that there are maximal electric and magnetic fields. So far, no observation reached these limits. The QED process also suggests that a derivation of the perturbative expansion of the g-factor from topological arguments is possible. The strand processes at QED interaction vertices also suggest an ab-initio estimate for the fine structure constant. In addition, the strand conjecture suggests an origin for the mass values of the electron and the other leptons. Previous estimates are improved. So far, no contradiction between the tangle model and experiment arises.

Keywords: quantum electrodynamics; strand conjecture; tangle model; electron mass; fine structure constant.

PACS numbers: 12.20.-m (quantum electrodynamics), 12.10.-g (unified field theories and models).

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1 The quest of quantum electrodynamics

After the successful development of quantum electrodynamics in the middle of the twentieth century, two questions remained open.

- What determines the mass of the electron?
- What exactly happens at the fundamental interaction vertex of quantum electrodynamics and how does this process determine the fine structure constant?

The answers to these questions are needed to understand the origin of all colours in nature. The present paper proposes such answers. They are as precise as possible at present. The answers derive from the recently proposed strand conjecture [1]. It conjectures that particles, space and horizons are made of fluctuating and unobservable strands of Planck length radius. Only strand crossings that change orientation – so-called *crossing switches* – are observable; the reason will become clear below. Particles are modelled as rational (i.e., unknotted) tangles of strands. Interactions are modelled as deformations of tangles. The strand conjecture implies the four fundamental interactions, yields the U(1), broken SU(2) and SU(3) gauge symmetries of the gauge interactions, and produces the observed spectrum of elementary bosons and fermions. In summary, the strand conjecture, as one of the first approaches so far, reproduces the Lagrangian of the standard model of particle physics. It also predicts the lack of extensions, of additional symmetry groups, of additional particles, of additional dimensions and of additional interactions.

Given the close agreement between the strand conjecture and experiments, one aspect of the conjecture becomes particularly interesting: strands imply the possibility to calculate the fundamental constants of nature, and in particular the mass of the electron and the fine structure constant. This aspect is explored in the present paper. Numerous ways to falsify the conjecture also arise. A thorough list is provided.

2 The origin of the conjecture

In the 1920s, Bohr defined quantum theory as consequence of the minimum observable action value $\hbar$ [2]. Dirac added the maximum energy speed c to quantum theory. From around 1929 onwards, he also regularly mentioned the so-called *string trick* or *belt trick* in his lectures. Illustrated in Figure 1, the trick describes spin 1/2 as result of tethered rotation.

The tether proposal was the first hint that nature might be built from extended constituents that are unobservable but have crossing switches that are observable. In 1980, Battey-Pratt and Racey understood that also the complete Dirac equation could be deduced from unobservable tethers attached to localized masses [3]. It thus appeared that *every quantum effect* might be thought as being due to unobservable extended constituents.

3 The strand conjecture and its fundamental principle

In the strand conjecture, everything in nature – matter, radiation, space, and horizons – is made of strands that fluctuate at the Planck scale. More precisely, the strand conjecture asserts:

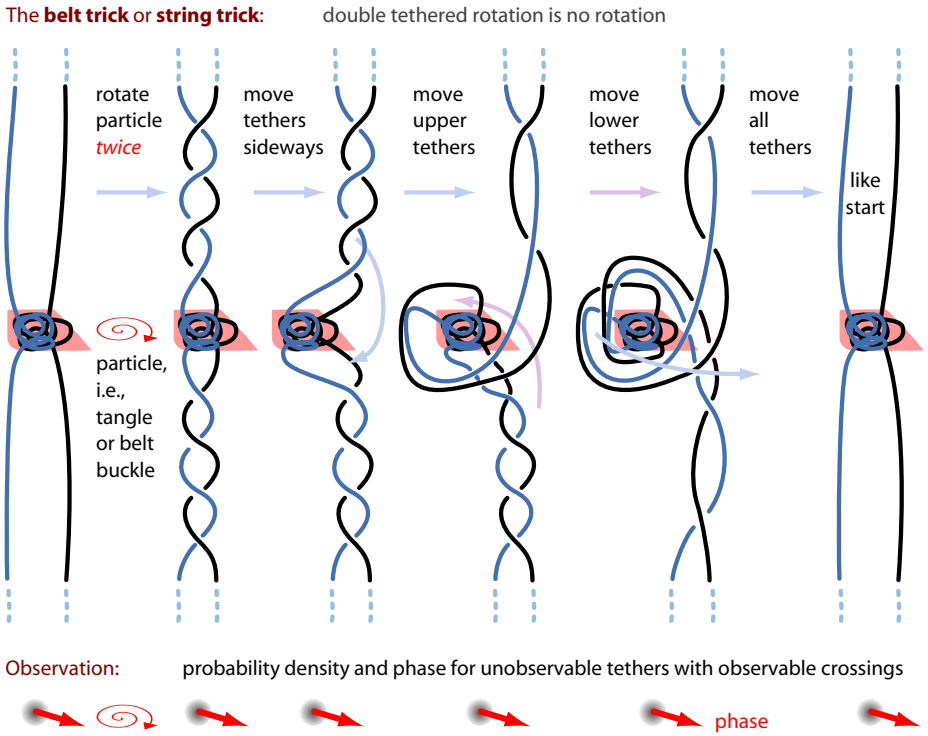

Figure 1: The *belt trick* or *string trick*: a rotation by 4π of a tethered particle, such as a belt buckle or a tangle, is equivalent to no rotation – when the tethers are allowed to fluctuate and untangle as shown. This allows a tethered particle to rotate continuously, without limits. Untangling tethers is impossible after a particle rotation by just 2π: tangles with 4 or more tethers have *spin 1/2*. In the strand conjecture, the belt trick also occurs spontaneously, through fluctuations. The frequency of the spontaneous belt trick determines particle mass.

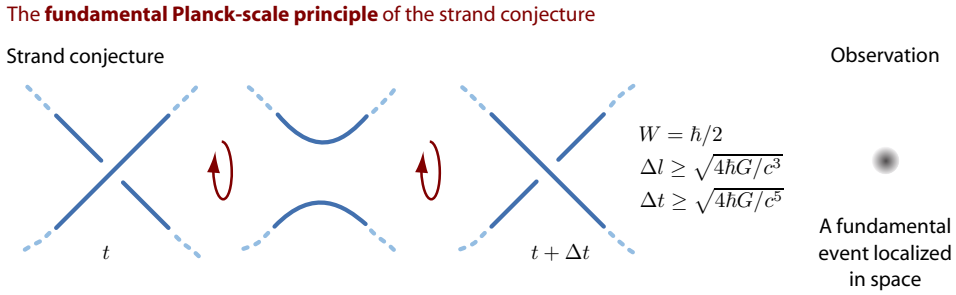

Figure 2: The fundamental principle of the strand conjecture concerns the simplest observation possible in nature: the almost point-like fundamental event results from a *skew strand crossing switch* at a given position in three-dimensional space. The strands themselves are not observable, are impenetrable, and are best imagined as having Planck size radius. The switch defines $\hbar/2$ as the unit of the action W. The Planck length and the Planck time arise, respectively, from the smallest and from the fastest crossing switch possible. On the issue of the fastest crossing switch, see section 11.

Space is a *network* of strands. Horizons are *weaves* of strands. Particles are *tangles* of strands. Though strands are unobservable, crossing switches are observable. Crossing switches determine the Planck units, and in particular $\hbar$, as illustrated in Figure 2.

Strands have no observable properties. Strands are best imagined as having Planck-size radius, in order to visualize the minimum length $\sqrt{4\hbar G/c^3}$. Strands imply that the minimum length is an unattainable limit that is thus itself unobservable. Strands cannot interpenetrate. The term *crossing* always implies an *apparent* crossing, when drawn in two dimensions. In three dimensions, strands are *always* at a distance, as illustrated in Figure 2 and Figure 3. In particular, crossing *switches* always arise via strand deformation, and in no other way.

All physical observables – from length to mass and field intensities – emerge from combinations of crossing switches. For example, any skew strand crossing allows defining the same observables that characterize a wave function, as illustrated in Figure 3. The geometry allows defining density, orientation, position, and phase. The freedom in the definition of the phase is at the origin of the freedom of gauge choice.

In the strand conjecture, elementary fermions are fluctuating *rational* tangles, i.e., unknotted open tangles. Elementary fermions are made of unknotted tethers. Their average crossing distribution is the wave function, and their average crossing switch distribution is their probability distribution. The connection is illustrated in Figure 4. For a particle tangle, the average phase, the average density, and the two average spin orientation angles define the two complex components of the Dirac wave function Ψ for a particle. For the mirror tangle, these averages define the two complex components of the antiparticle.

In his lectures, using a system equivalent to that of Figure 1, Dirac demonstrated that under rotation, a tethered core behaves like a spin 1/2 particle. Indeed, a double rotation of a tethered core can be undone by rearranging the tethers only; in contrast, this is impossible after a single rotation. Two tethered cores

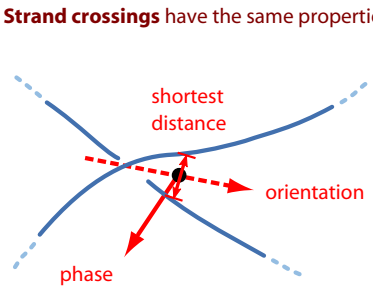

Figure 3: The geometric properties of (skew) strand crossings suggests a relation to wave functions. In both cases, position, density and orientation can be defined. In both cases, the absolute phase value around the orientation axis can be chosen freely. In contrast, in both cases, phase *differences* due to rotations around the axis of orientation are always uniquely defined.

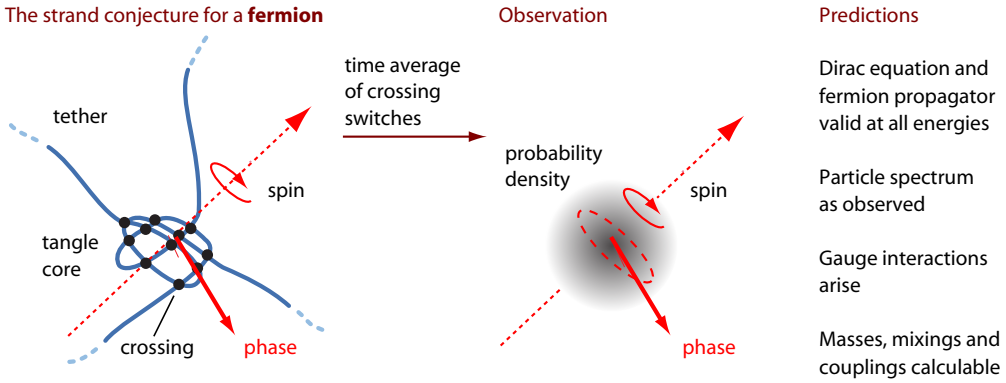

Figure 4: In the strand conjecture, the wave function is due to crossings and the probability density is due to crossing switches – after averaging. The quantum mechanical phase arises as the sum of all crossing phases. A Hilbert space arises. The tethers – strands that continue up to large spatial distances – lead to spin 1/2 behaviour under rotations and to fermion behaviour under particle exchange. The tangle model ensures that fermions have positive mass and move slower than light.

also imply that under exchange, tangle cores behave as fermions. Indeed a double exchange of tethered cores can be undone by rearranging the tethers only; in contrast, this is impossible after a single exchange. Both results applies independently of the number of tethers, as long as it is 3 or larger. Given that tethered particles reproduce spin (rotation) and particle exchange (a double translation), it does not take long to suspect that every quantum motion can be described with tethers.

In 1980, Battey-Pratt and Racey showed [3] that every tethered massive quantum particle – a tangle core in the case of the strand conjecture – is described by the Dirac equation for free particles. A freely moving quantum particle is thus described by a constantly rotating tangle core whose centre is moving. This situation can be described with wave functions: while the region of maximum density advances, the phase rotates. This situation can also be described with Feynman diagrams: advancing tangles with rotating cores model fermion propagators.

Introducing the fundamental principle, the result of Battey-Pratt and Racey can be summarized in the following concise way. Crossing switches of tangles naturally define four components for spin 1/2 wave functions: spin up and spin down, both for particles and antiparticles; antiparticles are defined as mirror tangles of particles. The Dirac equation arises because crossings switches in tangles reproduce spin 1/2, fermion behaviour, obey $v \leq c$ for speed and obey $W \geq \hbar/2$ for action. Because strands are unobservable, but crossing switches are observable, the Dirac equation is "just" a differential version of Dirac's string trick.

Probabilities, interference, entanglement, mixing, decoherence, antiparticles and all other quantum effects appear from strands, without modification. In short, tangles follow the Dirac equation [3, 4] and the Dirac Lagrangian. This implies: the usual expression for the fermion propagator follows from strands. Strands thus predict the lack of deviations from quantum theory. *Finding an energy or a situation for which quantum theory is not valid would falsify the strand conjecture.*

The fundamental principle also implies that Planck units are limits to physical observables in the quantum domain [4]. *Finding an elementary particle whose energy is larger than* $\sqrt{\hbar c^5/4G} = 6.1 \cdot 10^{18}\,\mathrm{GeV}$ *would falsify the strand conjecture.*

The description of quantum theory implies one new result. If elementary particles are rational tangles, their spectrum, their interactions, their masses and all their other properties are not free, but are *fixed* by their tangle structure.

4 Predictions about the particle spectrum

This section summarizes how strands lead to the observed particle spectrum of bosons and fermions, as told in detail elsewhere [1].

Elementary bosons can be made of one, two or three strands. More strands imply composite particles. The Reidemeister moves suggest that one-stranded bosons correspond to photons, three-stranded bosons to gluons, and two-stranded bosons to the W_1, W_2 or W_3. After symmetry breaking, when two-stranded boson tangles incorporate a vacuum strand, they yield the three-stranded W and the Z boson. The full list of boson tangles is given in Figure 5. No additional elementary boson appears possible. Photon and gluon tangles are massless, because they can rotate unhindered, whereas the W and the Z boson have

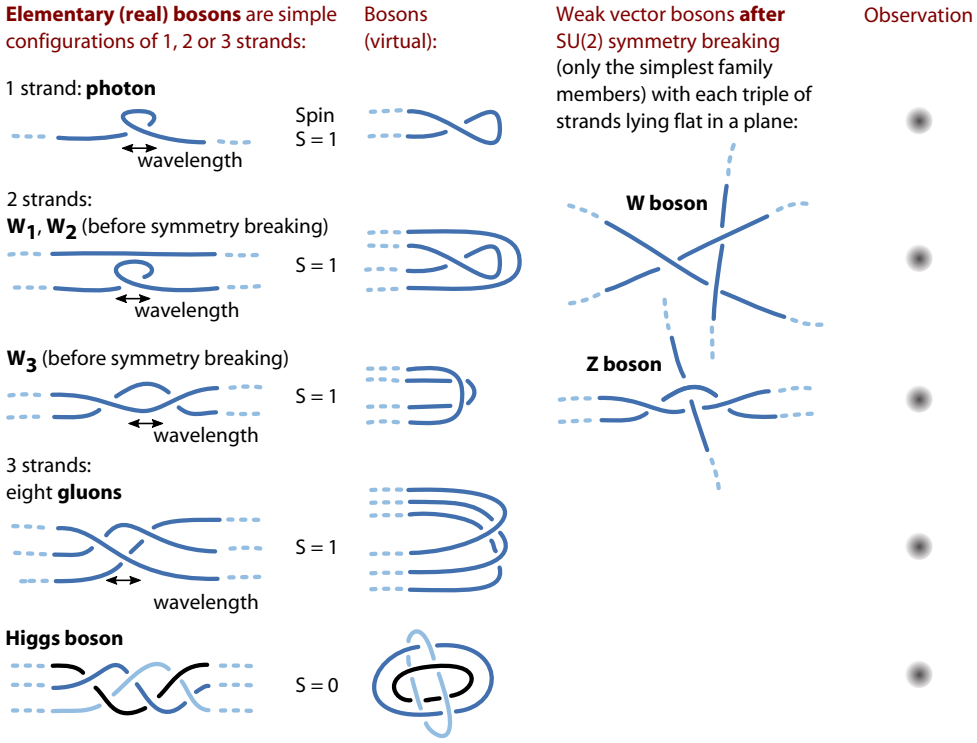

Figure 5: The conjectured tangles for the elementary bosons. These tangles determine their spin values and propagators, and ensure that photons and gluons are massless. No further elementary bosons are predicted to exist.

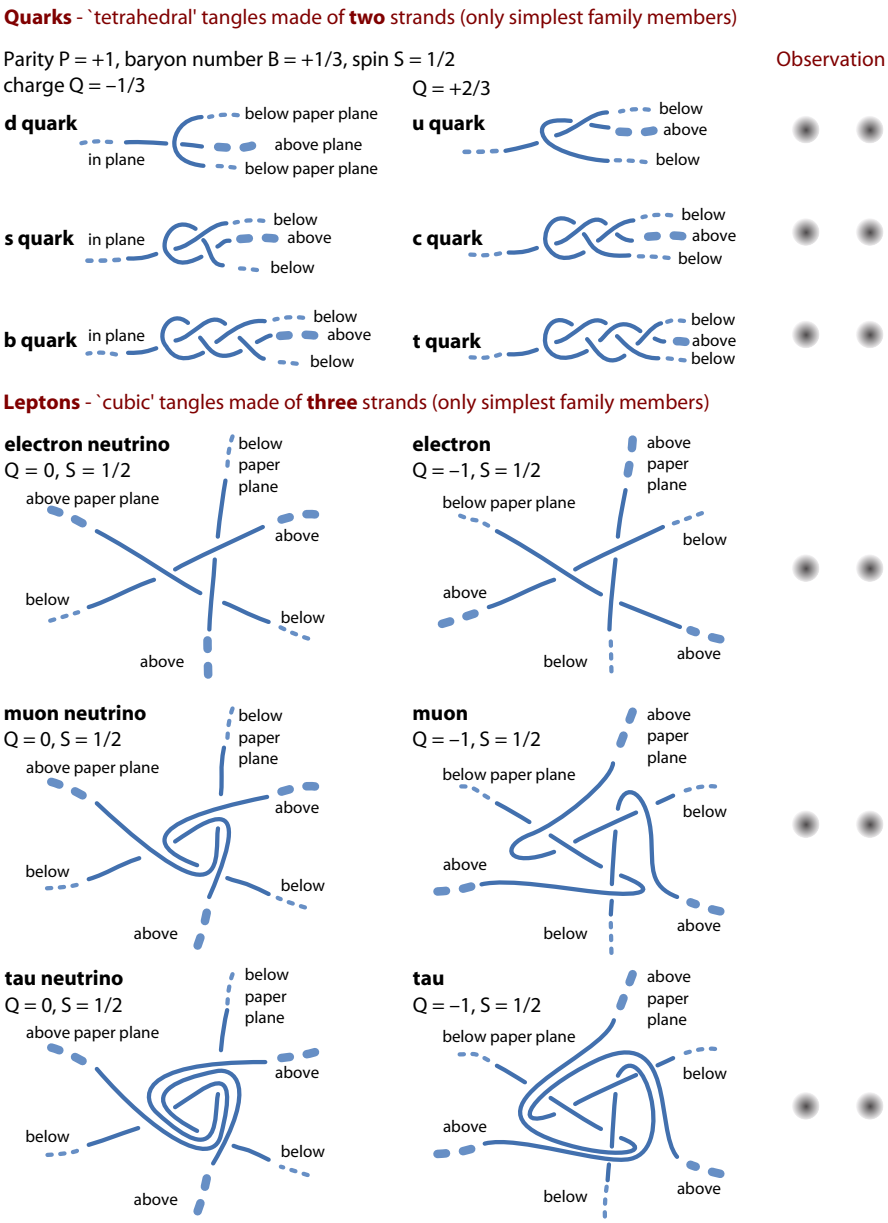

Figure 6: In the strand conjecture, elementary fermions are rational, i.e., unknotted tangles. This structure leads to coupling to the Higgs, as illustrated in Figure 9. Tangles produce positive mass values and exactly three generations. Tangles determine the specific fermion propagators. At large distances from the core, the tethers of the quark tangles follow the axes of a tetrahedron. Neutrino cores are simpler when observed in three dimensions: they are simply twisted triples of strands. At large distances from the core, the tethers of all lepton tangles follow the three coordinate axes. No additional elementary fermions appear.

mass.

The Higgs boson is a braid made of three strands. For all massive particles, Higgs braids can be added to the tangle core. The mass value is influenced by this – single or multiple – Higgs boson addition, as illustrated in Figure 9. The figure also shows that the Higgs couples to itself; it is thus massive. Massive particles – fermions or bosons – are thus described by an infinite 'family' of tangles that contain a simple core, that core plus one Higgs braid, that core plus two braids, etc. In contrast, massless particles are described by a single tangle, because no 'addition' of a Higgs braid to cores of massless particles is possible.

Elementary fermions can be made of two or three strands. One-stranded particle tangles cannot have spin 1/2 nor mass because the belt trick is not applicable. Two-stranded fermions are quarks, three-stranded fermions are leptons. Their tangles are given in Figure 6. Both quarks and leptons are limited to three generations by the coupling to the Higgs (and the three-dimensionality of space). The quark tangle assignments reproduce the quark model of hadrons [1, 4], including the correct retrodiction of which mesons violate CP and of all meson and hadron mass sequences. The neutrino assignments explain their handedness and their small mass. Additional elementary fermions are not possible. Particle mixing is also explained, as explained elsewhere [1].

The tangles of the elementary particles also determine their parities (from their mirror behaviour and their tangle core rotation), their spin (from the rotation behaviour of their tangle core), their baryon and lepton number (from the number of tethers), and all their other flavour quantum numbers (from the quark content). Strong and weak charges are introduced in reference [4]; electric charge is defined and explored in detail below.

In brief, in the strand conjecture, all observed quantum numbers are topological properties of particle tangles. Tangle classification leads to the fermion and boson spectrum observed in nature. The appearance of the gauge group structures from the boson structure is summarized below. *The discovery of any new elementary particle would falsify the tangle model.*

5 Predictions about gauge interactions

Summarizing earlier results [1], interactions are *tangle core deformations.* This is illustrated in Figure 7. Deformations of a localized tangle core modify the phase of a particle. This is the tangle model of how an externally applied field modifies the phase of a fermion wave function.

Deformations of spatial structures are described by gauge groups. In 1926, Reidemeister showed that every tangle core deformation is composed of three basic types: twists, pokes and slides [5]. Together they are now called the *Reidemeister moves*. They have a property that is not well known [1]:

Tangle core deformations determine the observed gauge groups U(1), broken SU(2) and SU(3).

In particular, the gauge group U(1) arises because twists can be generalized to arbitrary angles and concatenated. Also, a double twist can be rearranged to no twist at all, so that the non-trivial topology of U(1) arises. Electric charge is defined in section 8, as 1/3 of the (signed) sum of chiral crossings. Electric fields are volume densities of virtual photons, i.e., of twists. Magnetic fields are flow densities of twists.

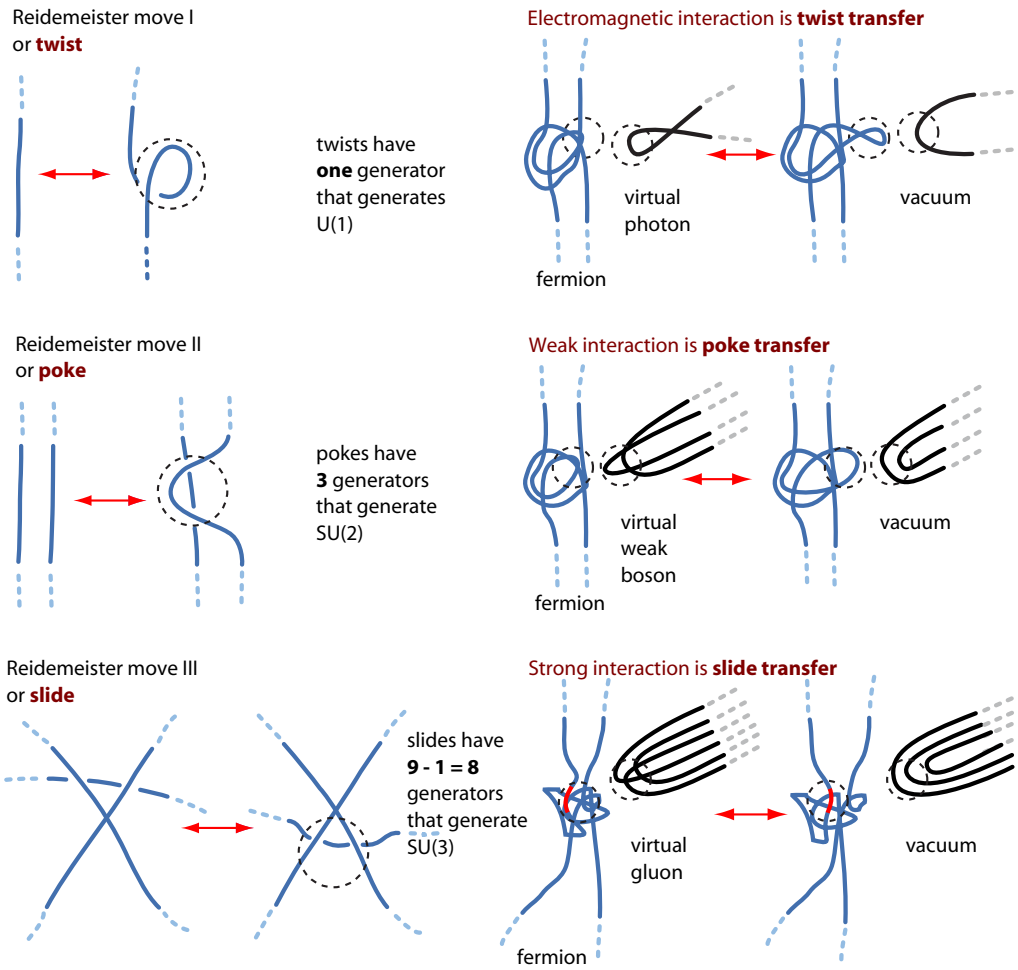

Figure 7: The three Reidemeister moves describe the three possible deformations of tangle cores [5]. They also determine the generators of the observed gauge interactions, determine the generator algebra, and thus fix the gauge group [1, 4]. Every generator rotates the region enclosed by a dotted circle by the angle π. The full gauge group arises by generalizing these rotations to arbitrary angles.

The gauge group SU(3) arises because slides reproduce the algebra of the eight generators of SU(3). This is the main result of the previous paper [1]. The full gauge group SU(3) arises because slides can be seen as local rotations by π, and these rotations can be generalized to arbitrary angles. CP violation does not occur in the strand conjecture for the strong interaction. Color charge is orientation of the three-ended side of a quark tangle in space. Color fields are densities of virtual gluons.

The gauge group SU(2) arises because pokes can be seen as rotations by the angle π around the three coordinate axes and thus form an SU(2) algebra. The generalization of these rotations to arbitrary angles yield the full SU(2) group. Strands imply that only massive fermions can exchange weak bosons. Due to the tangle structure of particles, SU(2) *breaking* arises, and so does maximal parity violation: this occurs because core rotations due to spin 1/2 'mix' with core deformations due to the group SU(2) of the weak interactions [1, 4].

All Feynman diagrams of the standard model are recovered [1]. This shown in Figure 8 and Figure 9. No other vertices arise. This result can be summarized in a simple way:

> The standard model results from tangle diagrams.

Because of the limited number of rational tangle families and because of the limited number of gauge interactions, the tangle model predicts that *there is no physics beyond the standard model.* This is the central prediction of the strand conjecture. *Any interaction or particle beyond or different from the standard model would falsify the strand conjecture.*

The following predictions are all based on an assumption and on a prediction: the assumption that the standard model derives from strands, and the prediction that the standard model is the valid description of particle physics. If this assumption or this prediction turn out to be wrong, the following sections are wrong as well.

6 The basic process of quantum electrodynamics

Strands imply that the electromagnetic interaction is due to the first Reidemeister move:

> The electromagnetic interaction is the – partial or complete – switch of a skew strand crossing in a charged tangle core. The switch is accompanied by the absorption or emission of a photon (twist).

The strand process at the basis of quantum electrodynamics (QED) is illustrated in Figure 10 and in Figure 11. In the absorption process, an approaching photon transfers its twist to a crossing that is part of a tangle core. The photon deforms the tangle crossing and thereby loses its own twist, becoming a vacuum strand. As a result, the photon disappears, i.e., it is absorbed. At the same time, the quantum phase of the tangle core changes, due to the crossing switch occurring in the particle tangle. In the emission process, a vacuum strand acquires a twist from the tangle core. In other terms, the absorption or the emission of a photon changes the phase of a charged particle tangle.

Because the emission or absorption of a photon occurs via the removal or addition of a twist, the process has a U(1) gauge symmetry. Indeed, twists can be generalized to arbitrary angles and can be

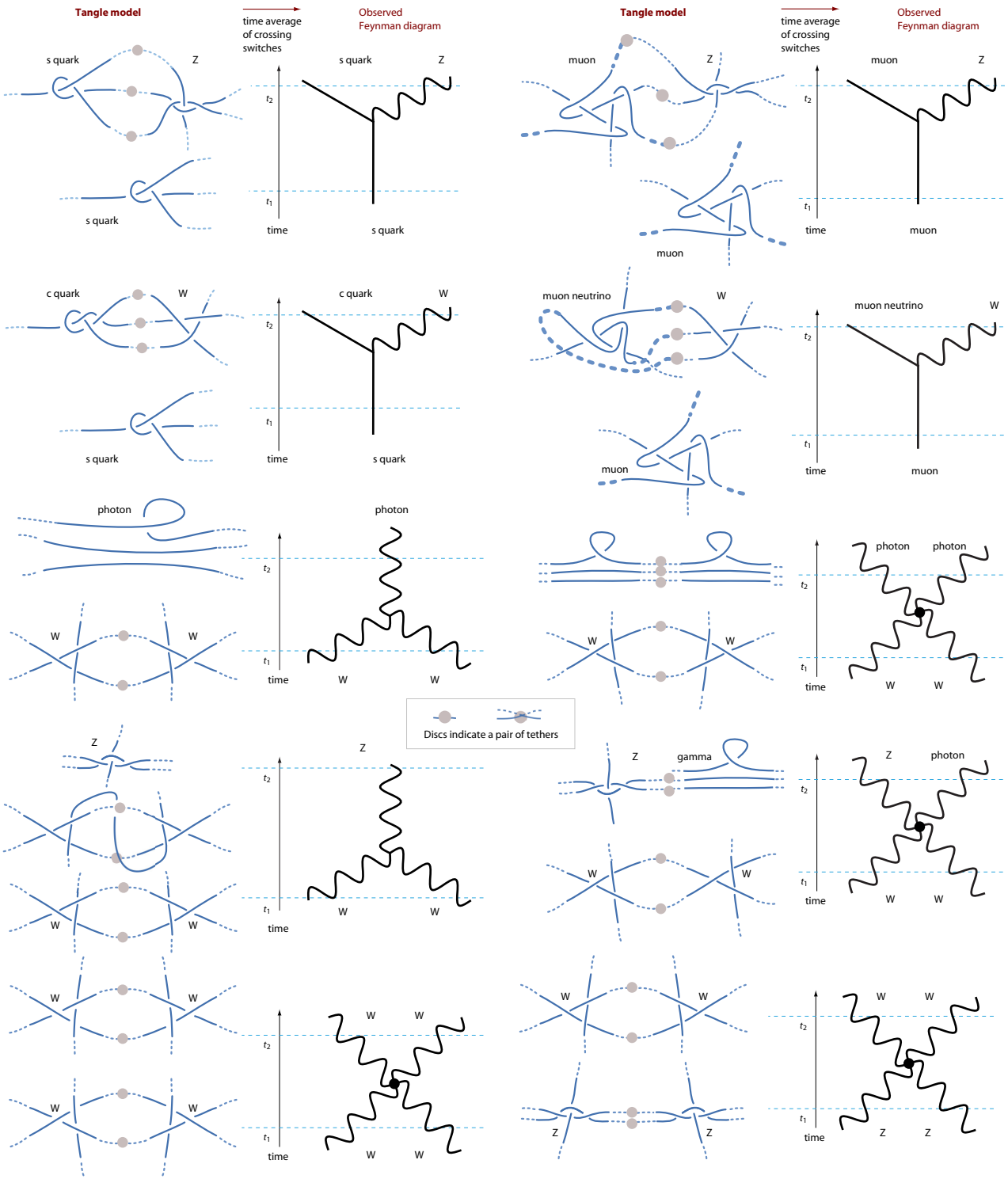

Figure 8: The vertices allowed by the topology of the fermion and boson tangles (part one).

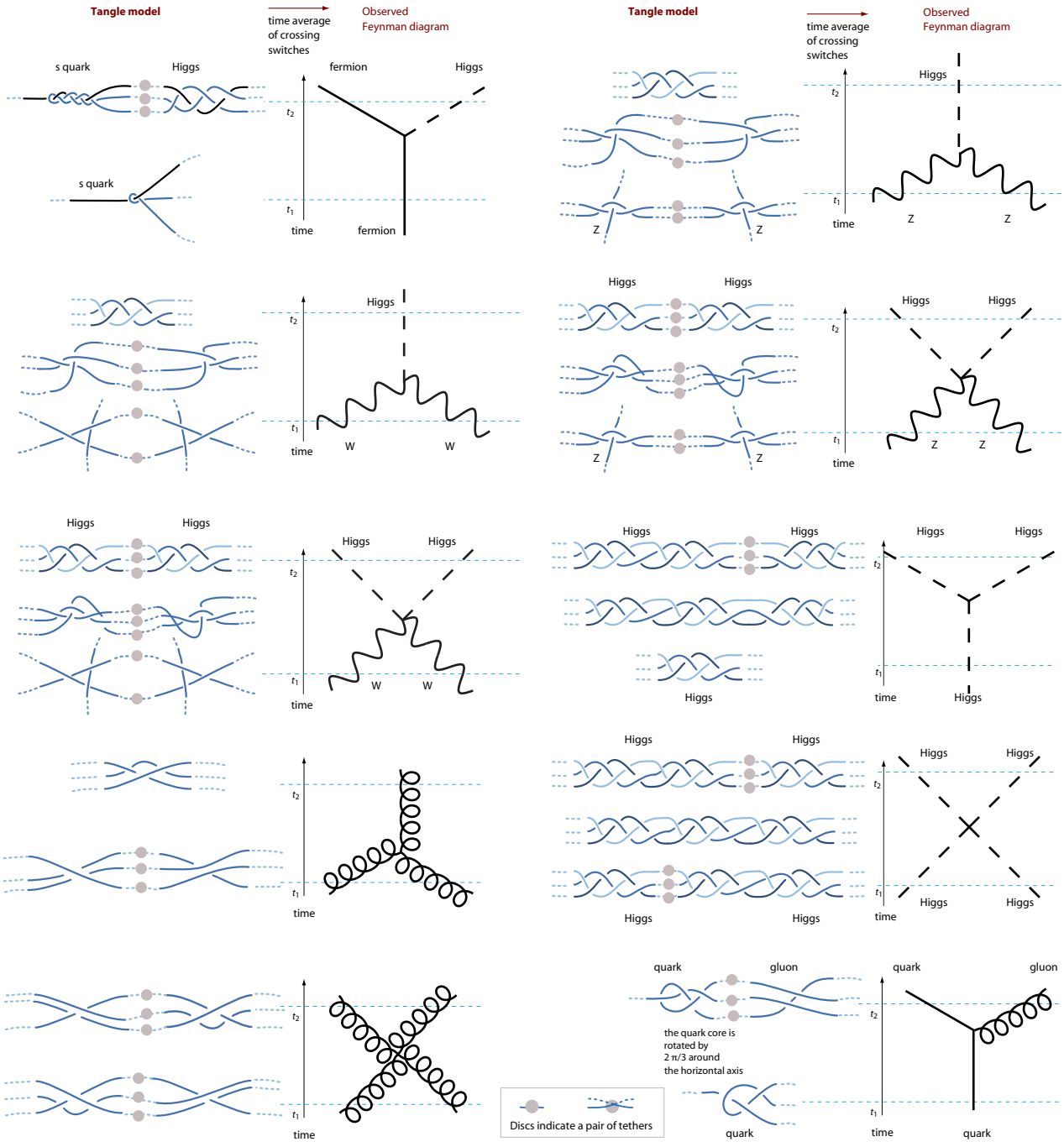

Figure 9: The vertices allowed by the topology of the fermion and boson tangles (part two).

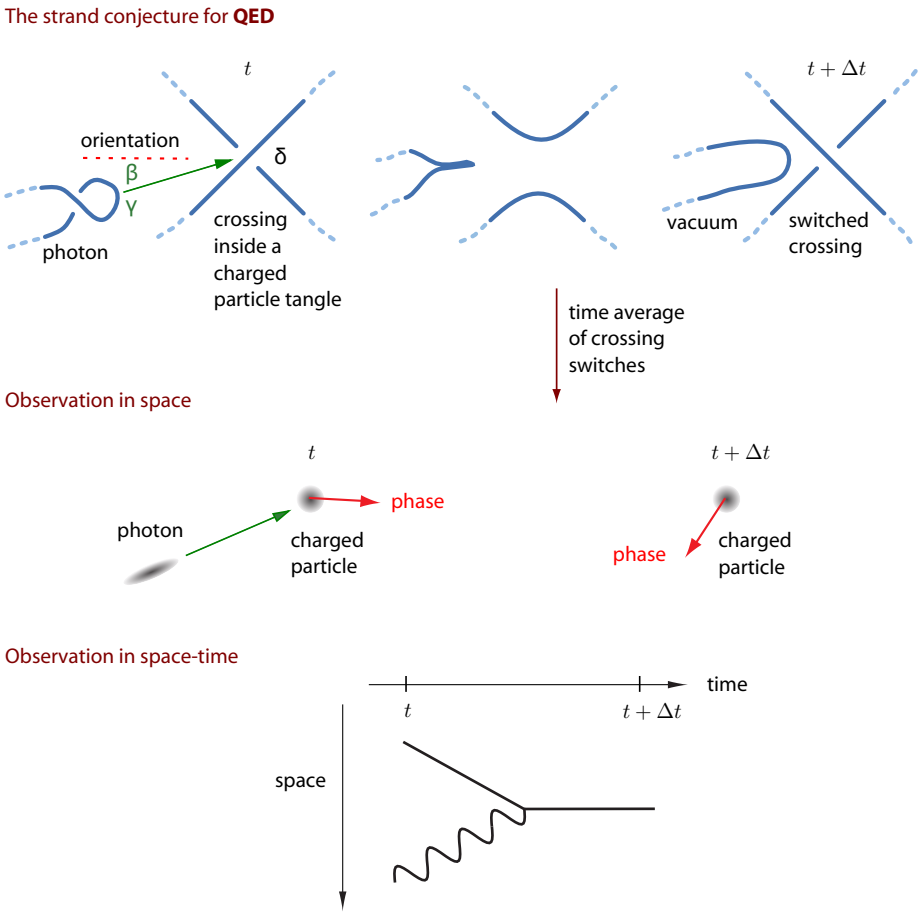

Figure 10: The geometry for the basic process of quantum electrodynamics (QED). Top: the absorption of a photon by a strand crossing, i.e., by a tangle region carrying the charge $e/3$, at large magnification. Centre: the corresponding observation at usual scales. Bottom: the corresponding Feynman vertex.

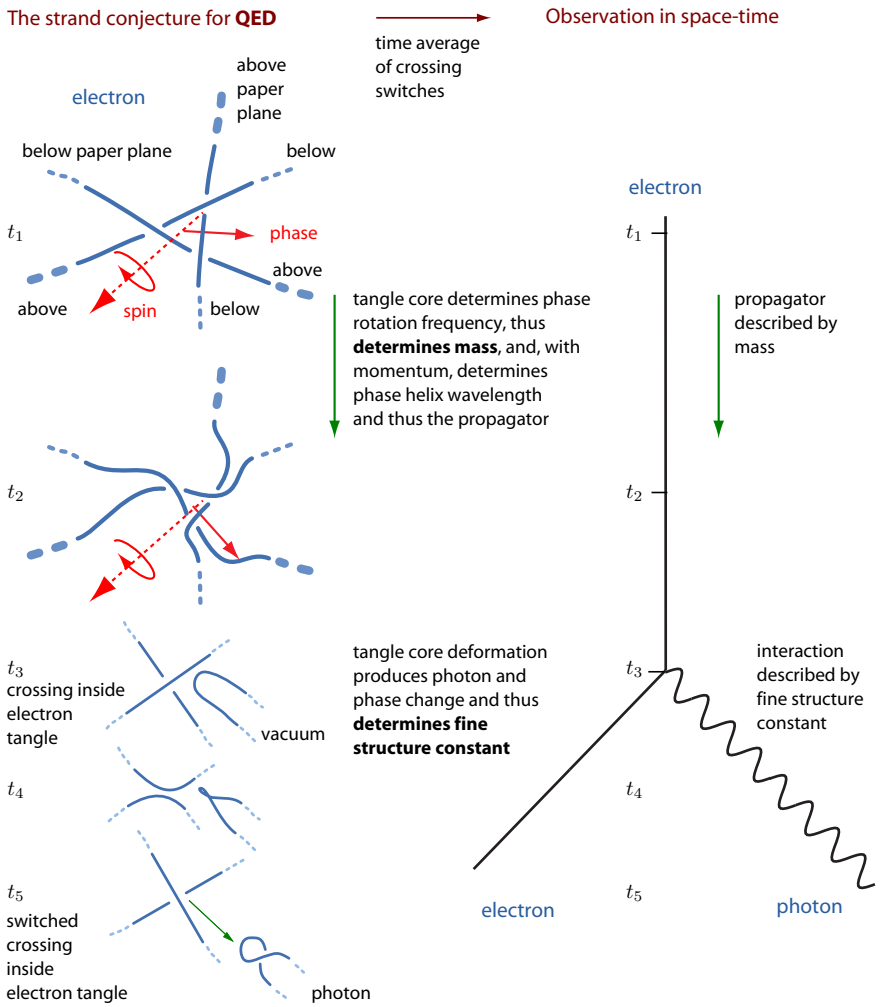

Figure 11: All of QED in one picture: in the strand conjecture, the electron mass and the fine structure constant are determined by the associated tangle (here the simplest family member) and its shape change under fluctuations. The electron mass is fixed by the average belt trick frequency during propagation. The fine structure constant is determined by the average phase jump in the electron core due to photon emission.

concatenated; a double twists can be undone just be moving the tethers, is thus equivalent to no twist at all. These properties define the group U(1).

Because the emission or absorption of a photon occurs via the removal or addition of a skew strand crossing, the phase of the charged particle changes.

7 Predictions about the fine structure constant

Because the emission or absorption of a photon occurs at a skew strand crossing, the tangle model of QED explains how a charged particle can have a spread-out wave function and still behave as (almost) point-like in interactions. The wave function is due to the tangle fluctuations of the complete tangle, which is spread out in space. In contrast, the interaction occurs at a single crossing, which is effectively point-like.

Because the emission or absorption of a photon occurs via the removal or addition of a skew strand crossing, the value of the fine structure constant is fixed: the (average) change of phase induced by a photon emission or absorption in a tangle core of unit charge determines the square root of the fine structure constant. Similar processes and arguments hold for the nuclear interactions.

Strands thus imply that all coupling constants, including the fine structure constant, are fixed, unique, smaller than one, and calculable. Because all Feynman diagrams of QED are reproduced, quantum field theory remains valid, and the three effective coupling constants run with energy. In particular, the fine structure constant is predicted to be constant over time and space – despite occasional opposite claims. In addition, the strand conjecture predicts that the fines structure constant and the other two coupling constants are *the same* for all particles and for all antiparticles. *Any experiment disproving the particle-independence, time-independence or position-independence of the coupling constants would falsify the strand conjecture.*

8 Predictions about electric charge and classical electrodynamics

In nature, a particle is electrically charged if it changes phase in a preferred direction when absorbing random photons. In the strand conjecture, the tangle cores of all *neutral* particles are *topologically achiral*, i.e., they are equal to their mirror image in the minimal crossing projection. As a result, neutral particles show no average phase change when they are hit by random photons. In contrast, *electrically charged* particles have *topologically chiral* tangle cores. Chiral cores differ from their mirror image in the minimal projection. Chiral cores have a preferred rotation direction when they absorb random photons: thus they are electrically charged. This definition of charge implies that electric charge has two signs, is quantized, is conserved and emits virtual photons. Electric charges of particles and antiparticles are predicted to be of exactly the same value, but of opposite sign. Electric charge only arises in particles with non-vanishing mass.

All observables are due to tangle crossing switches, and all strands have a minimum effective diameter. As a result, all observables are predicted to have limit values. For electric and magnetic fields, the limits are $E \leq c^4/4Ge = 1.9{\cdot}10^{62}\ \mathrm{V/m}$ and $B \leq c^3/4Ge = 6.3{\cdot}10^{53}\ \mathrm{T}$. So far, even the largest observed field

values, from particles to magnetars, are several orders of magnitude smaller than these limits. *Observing a field value beyond these limits would falsify the strand conjecture.*

Electric charge, as consequence of tangle chirality, is automatically conserved. All electric charges move slower than light. Photons are massless, and as a result, Coulomb's law holds. The topological definition of charge thus implies that Maxwell's equations hold [6, 7]. The strand conjecture thus implies classical electrodynamics.

In the tangle model, electric charge is a topological property of tangle cores. As explained in an earlier publication [1], every crossing in the minimal projection of a particle tangle leads to an electric charge $+e/3$ or $-e/3$. This assignment leads to the observed charge values for all elementary particles. In particular, this assignment thus explains why the charge of the proton is observed to be exactly equal, within measurement precision, to the charge of the positron. *Discovering an exception to charge quantization in multiples of* $e/3$ *– such as a charge* $e/2$ *or a millicharged particle – would falsify the strand conjecture.*

9 Predictions about electric dipole moments

The photon absorption process illustrated in Figure 10 implies that the charge 'units' $e/3$ or $-e/3$ inside an elementary particle are (at high energy) at average distances of the order of the Planck length. In particular, in the electron tangle there are three charge units of the same sign. Strands thus imply that the *intrinsic* electric dipole moment d is at most of the order the Planck length times the charge unit e, thus

$$d \lesssim e\, l_{\mathrm{Pl}} \quad . \tag{1}$$

The intrinsic dipole values predicted by the tangle model for elementary particles – either zero or negligibly small – are valid *provided* that the tangles of Figure 5 and Figure 6 are correct. In the strand conjecture, *additional* electric dipole moments arise because charges of opposite sign occur in the perturbation expansion, i.e., through strand fluctuations. These additional electric dipole moments occur in the same way as in the standard model. Strands thus predict the same electric dipole moment values as the standard model, where sizeable electric dipole moments arise only from operators of higher order. The dipole values predicted by the standard model and those predicted by the tangle model are still several or even many orders of magnitude smaller than the experimental limits. Hopefully, future experiments will allow stricter tests. *Discovering a sizeable electric dipole moment for electrons or other elementary particles would falsify the strand conjecture.*

10 Predictions about the g-factor and the anomalous magnetic moment

The exploration of the magnetic dipole moment of elementary particles fascinates many. A stone near Schwinger's grave shows his well-known formula for the g-factor

$$\frac{g}{2} = 1 + \frac{\alpha}{2\pi} \tag{2}$$

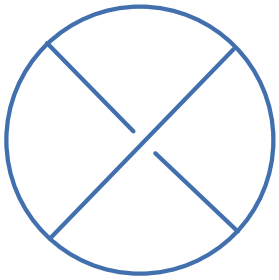

Figure 12: This topological configuration, following Broadhurst and Kreimer [11, 12], implies that $\zeta(3)$ arises in the second order coefficient of the g-factor. The strand conjecture produces the same configuration, if the circle is seen as representing the tangle core, and the two lines the two virtual photon twists pointing to the reader.

that is correct to first order in the fine structure constant α. The ratio $g/2$ is defined with the help of the magnetic (dipole) moment μ, the electric charge e, the spin S and the mass m as

$$\frac{g}{2} = \frac{\mu/e}{S/m} \; . \tag{3}$$

In the tangle model of particles, spin is due to the rigid rotation of the tangle core. Spin is thus due to the rotation of the *mass*, whereas the magnetic moment is due to the rotation of the *charge*. The ratio $g/2$ can thus be seen as the ratio between the two rotation frequencies.

To *zeroth order*, the rotation of the tangle mass is the *same* as the rotation of the tangle charge. The core rotates *rigidly* and $g/2$ is 1. Therefore, strands imply that the g-factor, to zeroth order, is equal to 2 for all charged particles – independently of spin. This applies to all charged rotating systems. This conclusion agrees with data [8] and theory [9]: also the W boson and charged black holes have a g-factor of 2.

The expression for the g-factor to *first order* arises when in addition to rigid core rotation, also core deformations are included. In the language of quantum electrodynamics, virtual photons can be emitted and reabsorbed. For each mass rotation, therefore, an additional, though partial, electrical rotation occurs. The importance of the effect is described by the electromagnetic coupling. The result is an additional phase jump given by the fine structure constant α. Strands thus imply that, to first order, $g/2$ is larger than 1 by the ratio between α and the full rotation 2π. This is Schwinger's formula given above.

One day it should be possible to determine in a similar way the expression for the *second order*, α^2, which was first calculated (correctly) by Petermann [10]. This would require to take into account how two virtual photon twists can tangle around each other or around the tethers of the electron tangle. The appearance of $\zeta(3)$ in the coefficient appears suggestive. In the tangle model, this appearance would be due to the integrations over the different geometric configurations in space for the two twisted loops that correspond to two virtual photons.

Broadhurst and Kreimer suspected such a possibility already long time ago [11, 12]. They argued that specific knots imply the appearance of specific transcendental numbers in the expression for the g-factor

at higher order in α. They argued that $\zeta(3)$, which appears at order α^2, is due to a specific topological configuration, illustrated in Figure 12. This configuration indeed arises when two virtual photons are emitted by an electron tangle. Following Broadhurst, generalizing the configuration of Figure 12 to more spokes is expected to lead to $\zeta(5)$, which arises at order α^3 [13]. And indeed, such a generalized configuration arises in the strand conjecture when more virtual photons occur. The tangle model for electrons and photons thus seems to provide an underlying physical model for this research.

In summary, the tangle model suggests the following conjecture: the perturbative expression for the g-factor arises through a mixture of topology and multiple integration. The appearance of transcendental numbers in the coefficients of the perturbative g-factor expansion appears to argue in favour of the tangle model. We recall that tangle processes reproduce all Feynman diagrams of the standard model [1], so that the conjecture is not as daring as it might seem. *Discovering a contradiction between the tangle model of the electron and the g-factor expansion would falsify the strand conjecture.*

11 Electromagnetism, measurements and minimum time

Strands explain the electric charge of particles from their tangle topology and the validity of Maxwell's equations. But strands do more: they explain the fundamental principle itself.

The fundamental principle defines all observations as being built from crossing switches. In addition, the basic QED process illustrates that *crossing switches are observable precisely because they couple to electromagnetic fields*. Every observation process and every measurement device – for measuring length, time, mass or any other physical observable – use electromagnetic fields. The use of electromagnetic fields is often forgotten – for example when we read the position of a pointer – but it is essential in every measurement. Without electromagnetism there are no measurements. Strands make this point forcefully, at the most fundamental level.

The coupling to electromagnetism also explains why a minimum time arises in the fundamental principle illustrated in Figure 2. Generally speaking, a crossing switch could take an arbitrary short time. But such a crossing switch would not and does not couple to the electromagnetic field: a photon wavelength shorter than a (corrected) Planck length is not possible. Such a crossing switch would not be observable and would not have any physical effect. In short, only crossing switches that take longer than a (corrected) Planck time have physical relevance.

12 Estimating the fine structure constant

The switch of a tangle crossing illustrated in Figure 10 also allows calculating the fine structure constant α. The figure shows the projection along the shortest distance s of a tangle crossing. In the neighbourhood of the shortest distance, each strand is parallel to the paper plane. Let δ be the angle between the two strands. The direction perpendicular to the paper plane is best imagined as the axis of a sphere, whose north pole is above the paper and whose south pole is below it. The paper plane is the equatorial plane. The photon incidence angle β shown in Figure 10 is a *longitude* on this sphere; it can vary from $-\delta/2$ to

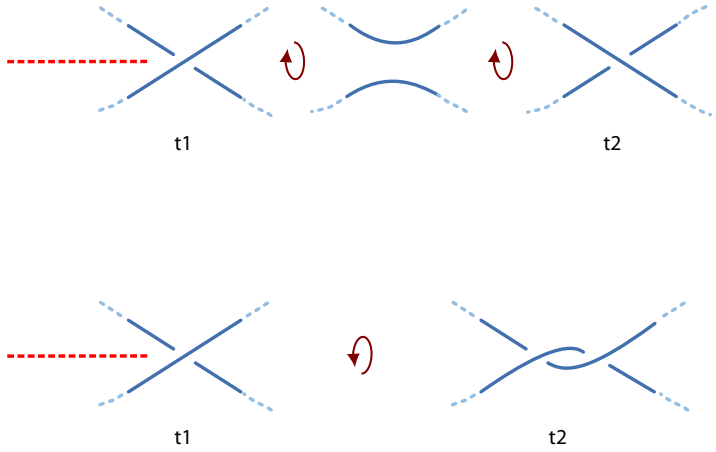

Figure 13: Two possible effects of photons on a crossing. Top: a twist can be decreased until it is untwisted and then changes sign. Bottom: a twist can be increased until it is doubled. The different probabilities of these two processes, when induced by a photon, are at the basis of the value of the fine structure constant.

$+\delta/2$. The other photon incidence angle γ is the angle from the incident photon direction to the paper plane; it thus corresponds to a *latitude* and varies from $-\pi/2$ to $+\pi/2$.

When a photon approaches a tangle core, it twists the part of the crossing surrounding it. The details of the photon incidence determine the *probability* p that a crossing switch takes place. The details also determine the *value* ν of the induced phase change. Both quantities can be estimated from geometry with more precision than done previously [1].

The *value* ν of the phase change that is due to a crossing switch can be estimated. The phase due to a crossing with angle δ is best described by an orientation vector oriented perpendicularly to the shortest distance of the crossing, as illustrated in Figure 3 and Figure 13. The freedom of choice of gauge allows to take as phase vector any vector that is perpendicular to the orientation axis. The orientation axis thus lies in the paper plane. The contribution of a strand crossing to the total tangle phase is expected to be $\sin\delta$. A switch that occurs due to a photon incident along the orientation axis of the crossing changes the crossing phase from the original value to its opposite; the phase change is thus $\nu = 2\sin\delta$. This is the value by which the phase of the total tangle changes when a photon arriving along the orientation axis is absorbed. For a general angle of photon incidence, the induced crossing switch is only *partial*. The *approximate* value for the phase change is expected to be

$$\nu = 2\sin\delta\cos\beta\cos\gamma\ . \tag{4}$$

The *probability* p that a photon induces a crossing switch will vanish for a photon arriving along the poles of the crossing. In other terms, perpendicularly to the paper plane, $p(\gamma = \pm\pi/2) = 0$. In addition, the probability for a crossing switch vanishes for photons arriving perpendicularly to either of the two strands. Furthermore, the switch probability is expected to be highest for the case $\gamma = \beta = 0$, i.e., for symmetrical incidence. For such a symmetrical incidence, the switch probability p is easiest to estimate.

The probability varies with the crossing angle δ and with the direction of the induced deformation. Photons can either change the crossing into one of the opposite sign, or change the crossing into a double one, as illustrated in Figure 13. The probabilities for the two processes differ. *Decreasing* the twist is more probable than *increasing* the twist, because the available (configuration) volume for a twist decrease is larger than for a twist increase. This is especially obvious for large values of the shortest distance s. The difference between the twist-decreasing and the twist-increasing probabilities is the value p that is sought. Both probabilities can be approximated.

The untwisting probability p_u will depend on the complement of the spherical angle spanned by the two strands when they are untwisted. In addition, the probability will depend on the ratio between the photon wavelength λ and the minimum strand distance s. The effect should yield a prefactor 1 for $\lambda > s$; the prefactor should decrease to 0 for smaller wavelengths. After averaging over all values for λ, in case of symmetric incidence, the probability will obey $p_u < (\cos \delta/2)^2$.

The probability p_i to increase the twist will also depend on the angle δ and on the strand distance s. In the case of symmetric incidence, the probability p_i will be a fraction of p_u, though one that is hard to estimate.

In the next step, the reasoning has to be generalized to a general angle of photon incidence. The *approximate* untwisting probability p_u for a crossing switch is expected to be $p_u \approx \cos\theta_1 \cos\theta_2$, where θ_n is the angle between the strand n and the direction of photon incidence. The *approximate* twist-increasing probability p_i is again estimated to be a fraction of p_u.

These approximations give the probability of a crossing switch for all possible geometries. The angles θ_i are determined by the scalar products $\cos\theta_1 = (\cos(\delta/2), \sin(\delta/2), 0) \cdot (\cos\beta\cos\gamma, \sin\beta\cos\gamma, \sin\gamma)$ and $\cos\theta_2 = (\cos(\delta/2), -\sin(\delta/2), 0) \cdot (\cos\beta\cos\gamma, \sin\beta\cos\gamma, \sin\gamma)$. This yields an approximate probability

$$p = p_u - p_i < p_u = (\cos(\delta/2)\cos\beta\cos\gamma)^2 - (\sin(\delta/2)\sin\beta\cos\gamma)^2 \ . \tag{5}$$

At present, it seems that difference between p and p_u can only be determined with computer simulations.

Calculating the fine structure constant requires averaging the phase change for an absorbed photon times the respective probability. The average has to take place over all photon incidence angles β and γ. This requires the use of the spherical surface element $(1/4\pi)\cos\gamma$. The calculation also requires averaging over all strand crossing configuration angles δ – using the probability density for strand angles given by $\sin\delta$. Averaging over all photon polarizations introduces a factor 1/2. Finally, multiplication by 3 gives the fine structure constant for a full unit charge, i.e., for a tangle core with three crossings.

In summary, the estimate of the electromagnetic coupling constant becomes

$$\sqrt{\alpha} < \frac{3}{8\pi} \int_{\delta=0}^{\pi/2} \int_{\beta=-\pi/2+\delta/2}^{\pi/2-\delta/2} \int_{\gamma=-\pi/2}^{\pi/2} p\ \nu\ \sin\delta\ \cos\gamma\ \mathrm{d}\gamma\,\mathrm{d}\beta\,\mathrm{d}\delta \approx 0.18 \approx \sqrt{1/31} \tag{6}$$

This estimate for an upper limit can be compared to the experimental value $\sqrt{1/137.03599914(3)} \approx 0.085$ at low energy or to the standard model prediction of $\sqrt{1/110(5)} \approx 0.095$ at Planck energy. There is *no agreement with experiment*.

On the one side, the proposed geometric approximation for the probabilities p and p_u is an educated guess. Improving it is not simple, but will reduce and thus improve the limit (6). In addition, the twist

calculation includes an admixture from the weak interaction. Indeed, the exchange of (half of) the weak W_3 boson tangle is similar to the exchange of a photon twist.

On the other side, the Planck scale model for the basic QED diagram remains promising: it reproduces all qualitative aspects of quantum electrodynamics. The approximate value for the fine structure constant is ab initio, unique, constant, and equal for all charged particles. *If the exact calculation disagrees with measurements, the strand conjecture would be falsified.*

13 Estimating the mass of the electron and the other leptons

As explained in the previous paper [1], the mass of a particle is due to the frequency of the belt trick. This description also implies that inertial mass and gravitational mass are equal. On the one hand, the belt trick generates a displacement and thus relates rotation and displacement, and this it what inertial mass does in the Dirac equation. Figure 1 gives a (pale) impression of this connection. On the other hand, the double tether twists generated by the belt trick correspond to virtual gravitons; the belt trick thus also determines gravitational mass. And because both mass values are due to the same mechanism, they are intrinsically equal.

In addition, the mass values of all elementary particles are predicted to be positive, fixed, unique and constant in time and space. Mass values are also equal for particles and antiparticles, i.e., for tangles and mirror tangles. And as usual, for several particles that are non-interacting, i.e., distant, the total mass is the sum of the single particles.

In the strand conjecture, every massive particle is represented by a *family* of tangles. In the following, the calculation only uses the simplest family member. The effect of the other family members on the mass has not been quantified yet.

In the strand conjecture, the tangle(s) of the electron will flatten at higher energy, leading to a *running* of the mass value. The effect is negligible to zeroth order, where only the volume of the tangle core plays a role. The flattening will change the mass somewhat. Strands thus predict that the mass value should increase slightly with (the logarithm of) the energy. This is indeed the case in the standard model, where the mass value only changes a few percent up to Planck energy. The small running of the mass value will be neglected in the following.

Strands imply that the particle mass depends on the tangle structure of the particle: more complex tangles – the number of tethers being equal – have larger mass. Mass values m for elementary particles are also much lower than the (corrected) Planck mass, because the probability for a belt trick or string trick is low: in particular, the probability is much lower than one crossing switch per corrected Planck time. Therefore,

$$m \ll \sqrt{\hbar c/4G} = 6.1 \cdot 10^{27}\,\mathrm{eV} \quad . \tag{7}$$

The inequality agrees with experiment. According to the strand conjecture, the low probability for the belt trick is thus the main reason that elementary particle masses are small compared to the Planck mass.

Estimating mass values of elementary particles requires estimating the probability of the string trick, i.e., of tethered rotation [1]. This process takes several steps, illustrated in Figure 1, in which the tethers

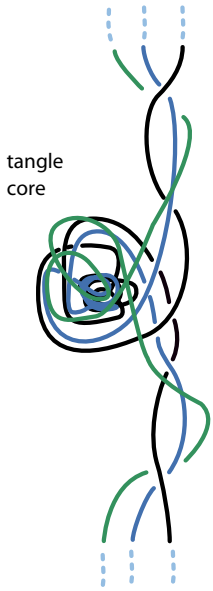

Figure 14: The strand configuration during the belt trick that yields a lower mass limit for the leptons.

follow specific configurations in space. A mass estimate requires to estimate the probability of the most improbable configuration. In Figure 1, this is the fifth configuration from the left. For the leptons, the main difference is that there are six tethers instead of four.

Estimating the probability of the belt trick turns out to be a difficult problem. The research literature does not contain any hint towards a solution. Research on polymers, on vortices, on cosmic strings, on string theory and on statistical knot theory have not explored the issue yet. The following ideas should thus be seen as first tentative steps into a dark room.

A probability estimate for the most improbable tangle configuration could be approached in the following way. In the belt trick, there is a frequency f for crossing switches due to core rotations and a multiplier n due to core deformations. The two processes assist each other:

$$m \approx f_{\text{core rotation}} \cdot n_{\text{core deformation}} \ . \tag{8}$$

This expression should cover every tethered structure, even black holes. Indeed, for a Schwarzschild black hole, only the second term – large in this case – plays a role [1]. In contrast, for an elementary particle, both terms – both small in this case – are expected to play a role. The second term, specifically, is responsible for the increase of the mass with tangle complexity.

For the core rotation of elementary particles, an estimate of the frequencies for the most improbable tangle configuration first requires to estimate the length of the tethers involved in that improbable configuration. At the Planck scale a fluctuating strand segment of length l realizes a specific configuration in space – specified within a minimum length – with a probability p

$$p \approx \mathrm{e}^{-l/l_{\min}} \ . \tag{9}$$

Here, it is assumed that the effective temperature at the Planck scale, which describes the fluctuations of strands, is the highest possible, i.e., the (corrected) Planck temperature.

For the configuration of Figure 14, the frequency appears to be

$$f_{\text{core rotation}} \approx \left(\mathrm{e}^{-l/l_{\min}}\right)^6 \cdot O(1) \; . \tag{10}$$

Here, l is now the additional length in one strand required to go round the core and produce the twists. The exponent 6 is due to the six tethers. The factor of order 1 describes the number of axes and tether separations that are possible. In this case, the factor $n_{\text{core deformation}}$ is assumed to have the lowest possible value, namely 1.

For the smallest possible core diameter, l will be about 12 minimum lengths. This yields

$$\frac{m}{\sqrt{\hbar c/4G}} > \mathrm{e}^{-72} = 5.4 \cdot 10^{-32} \quad \text{or, equivalently} \quad m > 0.3\,\mathrm{meV} \; . \tag{11}$$

Improving this lower estimate for the mass of leptons should not be impossible.

An upper mass estimate can be found when the core diameter d of the lepton tangles is taken into account. For such a tangle core, the factor $n_{\text{core deformation}}$ becomes important. It is expected that this number depends on the size of the 'volume' of the core and on the number of tethers, because every crossing inside the core can lead to crossing switches. A steep dependence is expected, of the type

$$n_{\text{core deformation}} \approx (d^3 \cdot d^3)^6 \tag{12}$$

For a large core, d is about 3. This yields an upper mass bound

$$\frac{m}{\sqrt{\hbar c/4G}} < \mathrm{e}^{-72} \cdot 3^{36} = 8.1 \cdot 10^{-15} \quad \text{or, equivalently} \quad m < 50\,\mathrm{TeV} \; . \tag{13}$$

It should be possible to improve also this bound.

In comparison, the corrected Planck mass is $\sqrt{\hbar c/4G} = 6.1 \cdot 10^{27}\,\mathrm{eV}$, so that the experimental mass of the electron of $0.5\,\mathrm{MeV}$ corresponds to $0.8 \cdot 10^{-22}$ corrected Planck masses. The measured value of the electron mass is thus compatible with the – very rough – strand limits just deduced. In fact, the limits (11) and (13) are valid for all leptons. For neutrinos, they also suggest a lower mass bound. And indeed, the limits do not disagree with experiments.

On the one hand, the mass estimates for the electron and the other leptons are not precise. Indeed, the specific tangle topology was not used in the estimates. And the estimates themselves are extremely rough. Furthermore, the running with energy and the effects of the other tangles of each lepton tangle family (i.e., the Higgs coupling) were neglected. The two mass estimates thus should be taken *cum grano salis*. On the other hand, the mass estimates are ab initio, unique, constant over time and space, and equal for particles and antiparticles. *Particle masses that are observed to be different across the universe would falsify the strand conjecture.*

More precise estimates of particle masses require better analytical approximations or efficient computer simulation programs. This challenge remains open. *The failure to reproduce, with more precise methods, any one of the observed lepton mass value would falsify the strand conjecture.*

14 Discussion and outlook

The tangle model has several unusual aspects. First, the model is counter-intuitive: it requires to get used to the idea that every particle in nature is tethered. Second, the tangle model proposes a microscopic model for quantum theory, despite the failure, without exception, of all past attempts in this domain. Third, the tangle model arises directly from Planck-scale physics, without any additional concepts or structures. Fourth, the tangle model describes events, interactions, physical processes and the standard model with simple pictures. Despite these unusual aspects, the strand conjecture agrees with the standard model of particle physics. Strands imply that this agreement is correct up to particle energies very close to the Planck energy or to electric fields very close to the Planck values.

So far, experiments in QED do not reach Planck scales. This implies that the proposed tangle structure of particles cannot be tested directly. However, it is suggested that the expansion of the g-factor can provide a hint that the proposed tangle structures for the leptons are correct. Also observations in the non-perturbative domain of QED, in particular near the electric or magnetic field limits, would allow stricter tests of the conjecture. But such tests do not seem possible, neither in astrophysics nor in the particle physics. So far, the strictest tests for the strand conjecture seem to be calculations of the particle masses and of the fine structure constant. However, the estimates proposed above are not precise enough to allow definite statements in favour or against the conjecture. In the case that future, more precise calculations disagree with experiment, the strand conjecture would be falsified. In the opposite case, i.e., if the conjecture agrees with experiment, the origin of all colours in nature would finally be explained.

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References

[1] C. Schiller, *A conjecture on deducing general relativity and the standard model with its fundamental constants from rational tangles of strands*, Physics of Particles and Nuclei **50** (2019) 259–299.

[2] N. Bohr, *Atomtheorie und Naturbeschreibung*, Springer (1931).

[3] E. Battey-Pratt and T. Racey, *Geometric model for fundamental particles*, International Journal of Theoretical Physics **19** (1980) 437–475.

[4] C. Schiller, *The Strand Model – A Speculation on Unification*, MotionMountain.net (2009) chapter 8.

[5] K. Reidemeister, *Elementare Begründung der Knotentheorie*, Abhandlungen aus dem Mathematischen Seminar der Universität Hamburg **5** (1926) 24–32.

[6] J.A. Heras, *Can Maxwell's equations be obtained from the continuity equation?*, American Journal of Physics **75** (2007) 652–657.

[7] L. Burns, *Maxwell's Equations are Universal for Locally Conserved Quantities*, Advances in Applied Clifford Algebras, **29** (2019) 62.

[8] S. Mele, *Physics of W bosons at LEP*, Physics Reports **403–404** (2004) 255–270.

[9] B.R. Holstein, *How large is the "natural" magnetic moment?*, American Journal of Physics **74** (2006) 1104.

[10] A. Petermann, *Fourth order magnetic moment of the electron*, Helvetica Physic Acta **30** (1957) 407–408.

[11] D.J. Broadhurst and D. Kreimer, *Association of multiple zeta values with positive knots via Feynman diagrams up to 9 loops*, Physics Letters B **393** (1997) 403–412.

[12] D. Kreimer, *How useful can knot and number theory be for loop calculations?*, Acta Physica Polonica B **29** (1998) 2865–2873.

[13] S. Laporta and E. Remiddi, *The analytical value of the electron* $(g-2)$ *at order* α^3 *in QED*, Physics Letters B **379** (1996) 283–291.